

# VEHICULAR MOTION CONTROL APPARATUS AND VEHICULAR MOTION CONTROL METHOD

## INCORPORATION BY REFERENCE

5 [0001] The disclosure of Japanese Patent Application No. 2002-313696  
filed on October 29, 2002, including the specification, drawings, and abstract is  
incorporated herein by reference in its entirety.

## BACKGROUND OF THE INVENTION

### 1. Field of the Invention

10 [0002] The invention relates to a vehicular motion control apparatus and a  
vehicular motion control method. More specifically, the invention relates to a  
vehicular motion control apparatus and a vehicular motion control method for  
controlling motion of a vehicle using a steering angle detected by a steering angle  
sensor.

### 2. Description of the Related Art

15 [0003] According to a vehicular motion control apparatus for an automobile  
or the like as a known example, a target behavior of a vehicle is calculated at least on  
the basis of a detected value of a steering angle relative to a neutral position of a  
steering wheel, and motion of the vehicle is controlled in accordance with a  
20 difference between a target value of the behavior of the vehicle and an actually  
measured value of the behavior of the vehicle. In this apparatus, if the neutral  
position of the steering wheel has not been detected, a steering angle is estimated  
from a steering angle stored during the last off-period of an ignition switch and a  
cumulative value of the number of pulses delivered from a steering angle sensor  
25 after the turning-on of the ignition switch, so as to control motion of the vehicle.  
This vehicular motion control apparatus is disclosed, for example, in Japanese Patent  
Application Laid-Open No. 10-287262.

[0004] In the aforementioned vehicular motion control apparatus, however, a means for storing a steering angle during the last off-period of the ignition switch is required. Also, if a driver operates the steering wheel to cause a change in steering angle before the ignition switch is turned on and after the ignition switch has been turned off, it is impossible to precisely detect a steering angle. This causes a problem in that motion of the vehicle cannot be controlled suitably.

[0005] There is also known a method of detecting on the basis of a yaw rate or the like of a vehicle that the vehicle is traveling straight on at a constant speed, and calibrating a neutral point of a steering angle sensor when the vehicle is traveling straight on at a constant speed. In the case of this method, however, there is a problem in that the neutral point of the steering angle sensor cannot be calibrated unless it is detected that the vehicle is traveling straight on at a constant speed.

#### SUMMARY OF THE INVENTION

[0006] The invention has been made in consideration of the aforementioned problems in a vehicular motion control apparatus that controls motion of a vehicle using a steering angle detected by a steering angle sensor. It is a main object of the invention to precisely detect a steering angle by means of a steering angle sensor and to suitably control motion of a vehicle without requiring any means for storing a steering angle even when an ignition switch is off and even unless the vehicle is traveling straight on at a constant speed, by estimating a plurality of steering angles from a steering angle detected by the steering angle sensor and focusing attention on the magnitudes of differences between an actual vehicle state quantity and a plurality of target vehicle state quantities calculated on the basis of the steering angles.

[0007] In order to solve the problems stated above, a vehicular motion control apparatus in accordance with a first aspect of the invention has a steering operator operated by a driver, a steering angle sensor capable of detecting an absolute rotational angle of the steering operator, and an actual vehicle state quantity detector. If a reference rotational position of the steering angle sensor has not been

determined, the control apparatus calculates a plurality of target vehicle state quantities on the basis of a plurality of steering angles estimated from a steering angle detected by the steering angle sensor, and controls motion of the vehicle on the basis of the minimum one of differences between an actual vehicle state quantity and the target vehicle state quantities.

[0008] A vehicular motion control apparatus in accordance with a second aspect of the invention has a steering operator operated by a driver, a steering angle sensor capable of detecting an absolute angle of the steering operator, and an actual vehicle state quantity detector. The control apparatus calculates a plurality of target vehicle state quantities on the basis of a plurality of steering angles estimated from a steering angle detected by the steering angle sensor, determines a reference rotational position of the steering angle sensor on the basis of a steering angle corresponding to the minimum one of differences between an actual vehicle state quantity and the target vehicle state quantities, and then calculates a steering angle for controlling motion of the vehicle on the basis of the steering angle detected by the steering angle sensor and the determined reference rotational position.

[0009] In the apparatus of the second aspect, it is also appropriate that time averages of differences between an actual vehicle state quantity and the target vehicle state quantities be calculated, and that a reference rotational position of the steering angle sensor be determined on the basis of a steering angle corresponding to the minimum one of the time averages.

[0010] In general, the lock-to-lock number of revolutions of a steering operator such as a steering wheel is larger than 1. Therefore, if a reference rotational position of the steering angle sensor has not been determined, a true steering angle cannot be specified on the basis of a steering angle detected by the steering angle sensor. However, a plurality of steering angles are estimated as possibly true steering angles. One of the steering angles thus estimated is equal to a true steering angle.

[0011] Thus, if a plurality of target vehicle state quantities are calculated on the basis of a plurality of estimated steering angles and differences between an actual vehicle state quantity and target vehicle state quantities are calculated, the difference between the actual vehicle state quantity and the target vehicle state quantity calculated on the basis of the estimated steering angle equal to a true steering angle is smaller than the differences between the actual vehicle state quantity and the target vehicle state quantities calculated on the basis of the other estimated steering angles. Therefore, the minimum one of the differences between the actual vehicle state quantity and the target vehicle state quantities calculated on the basis of the estimated steering angles is equal to the difference between the actual vehicle state quantity and the target vehicle state quantity calculated on the basis of the true steering angle.

[0012] According to the aforementioned first aspect, if a reference rotational position of the steering angle sensor has not been determined, a plurality of target vehicle state quantities are calculated on the basis of a plurality of steering angles estimated from a steering angle detected by the steering angle sensor, and motion of the vehicle is controlled on the basis of the minimum one of differences between an actual vehicle state quantity and target vehicle state quantities. Therefore, motion of the vehicle can be suitably controlled on the basis of a difference equal to the difference between the actual vehicle state quantity and the target vehicle state quantity calculated on the basis of a true steering angle.

[0013] As described above, the minimum one of the differences between an actual vehicle state quantity and a plurality of target vehicle state quantities calculated on the basis of a plurality of estimated steering angles is equal to a difference between the actual vehicle state quantity and the target vehicle state quantity calculated on the basis of a true steering angle. Therefore, a reference rotational position of the steering angle sensor can be determined as a steering angle detection reference position such as a neutral position on the basis of a steering angle corresponding to the minimum one of the differences between the actual vehicle

state quantity and the target vehicle state quantities even unless the vehicle is traveling straight on at a constant speed, and a true steering angle can be calculated on the basis of the reference rotational position thus determined and the steering angle detected by the steering angle sensor.

5           [0014] According to the aforementioned second aspect, a plurality of target vehicle state quantities are calculated on the basis of a plurality of steering angles estimated from a steering angle detected by the steering angle sensor, a reference rotational position of the steering angle sensor is determined on the basis of a steering angle corresponding to the minimum one of the differences between an  
10   actual vehicle state quantity and the target vehicle state quantities, and a steering angle for controlling motion of the vehicle is then calculated on the basis of the reference rotational position thus determined and the steering angle detected by the steering angle sensor. Therefore, a steering angle can be precisely detected by means of the steering angle sensor and motion of the vehicle can be suitably  
15   controlled without requiring any means for storing a steering angle even when an ignition switch is off and even unless the vehicle is traveling straight on at a constant speed.

          [0015] Furthermore, in the aforementioned second aspect, time averages of differences between an actual vehicle state quantity and target vehicle state  
20   quantities are calculated, and a reference rotational position of the steering angle sensor is determined on the basis of a steering angle corresponding to the minimum one of the time averages. Therefore, in comparison with a case where a reference rotational position of the steering angle sensor is determined on the basis of a steering angle corresponding to the minimum one of differences between an actual  
25   vehicle state quantity and target vehicle state quantities, a reference rotational position of the steering angle sensor can be determined with the influence of traveling situations of the vehicle and the like being reduced more substantially.

          [0016] A vehicular motion control method in accordance with a third aspect of the invention comprises the steps of detecting an absolute rotational angle of a

steering operator operated by a driver, detecting an actual vehicle state quantity, calculating a plurality of target vehicle state quantities on the basis of a plurality of steering angles estimated from a detected steering angle if a reference rotational position of the steering angle sensor has not been determined, controlling motion of the vehicle on the basis of the minimum one of differences between the target state quantities and the actual vehicle state quantity.

[0017] A vehicular motion control method in accordance with a fourth aspect of the invention comprises the steps of detecting an absolute rotational angle of a steering operator operated by a driver by means of a steering angle sensor, detecting an actual vehicle state quantity, calculating a plurality of target vehicle state quantities on the basis of a plurality of steering angles estimated from a detected steering angle, determining a reference rotational position of the steering angle sensor on the basis of a steering angle corresponding to the minimum one of differences between an actual vehicle state quantity and the target vehicle state quantities, and then calculating a steering angle for controlling motion of the vehicle on the basis of the detected steering angle and the determined reference rotational position.

#### **BRIEF DESCRIPTION OF THE DRAWINGS**

[0018] Fig. 1 is a schematic block diagram showing a vehicular motion control apparatus in accordance with a first preferred embodiment of the invention.

[0019] Fig. 2 is a flowchart showing a motion control routine of the first embodiment.

[0020] Fig. 3 is a flowchart showing a reference rotational position determining routine in a step 200 of the flowchart shown in Fig. 2.

[0021] Fig. 4 is a flowchart showing a reference rotational position determining routine in a vehicular motion control apparatus in accordance with a second preferred embodiment of the invention.

[0022] Figs. 5A, 5B and 5C are explanatory views showing relationships between true steering angle  $\theta$  and steering angle  $\phi$  detected by a steering angle sensor.

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#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0023] Some preferred embodiments (hereinafter referred to simply as embodiments) of the invention will be described in detail with reference to the accompanying drawings.

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[0024] Fig. 1 is a schematic block diagram showing a vehicular motion control apparatus in accordance with the first embodiment of the invention.

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[0025] Referring to Fig. 1, reference symbols 10FL and 10FR denote front-left and front-right wheels of a vehicle 12 respectively, while reference symbols 10RL and 10RR denote rear-left and rear-right wheels of the vehicle 12 respectively. The rear-left and rear-right wheels 10RL and 10RR are driving wheels of the vehicle 12. The front-left and front-right wheels 10FL and 10FR, which are driven wheels and wheels to be steered, are steered by a rack-and-pinion power steering unit 16 via tie rods 18L and 18R respectively. The rack-and-pinion power steering unit 16 is driven in response to the turning of a steering wheel 14 by a driver.

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[0026] A hydraulic circuit 22 of a brake unit 20 controls braking pressures applied to wheel cylinders 24FR, 24FL, 24RR and 24RL, whereby braking forces applied to the respective wheels are controlled. Although not shown in Fig. 1, the hydraulic circuit 22 includes a reservoir, an oil pump, various valve gears, and the like. Braking pressures applied to the wheel cylinders are usually controlled by a master cylinder 28 that is driven in accordance with the driver's operation of depressing a brake pedal 26. If necessary, braking pressures applied to the wheel cylinders are controlled by an electronic control unit 30, as will be described later in detail.

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[0027] A steering column is provided with a steering angle sensor 34 that detects a rotational angle of a steering shaft 32 as a steering angle  $\phi$ . The vehicle

12 is provided with a yaw rate sensor 36 that detects a yaw rate  $\gamma$  of the vehicle and with a vehicle speed sensor 38 that detects a vehicle speed  $V$ . The steering angle sensor 34 and the yaw rate sensor 36 detect a steering angle and a yaw rate respectively on the assumption that they assume positive values when the vehicle makes a right turn.

[0028] Especially in the illustrated embodiment, the lock-to-lock number of revolutions of a steering system of the power steering unit 16 is set as 3. The steering angle sensor 34 detects a steering angle  $\phi$  as an absolute rotational angle of the steering shaft 32 with respect to a reference rotational position. Thus, as shown in Figs. 5A, 5B and 5C, if determination of a reference rotational position has not been completed, the true steering angle  $\theta$  may be  $\phi$ ,  $\phi+360^\circ$  or  $\phi-360^\circ$ . By determining the reference rotational position as a neutral position corresponding to a straight traveling state of the vehicle, the true steering angle  $\theta$  is specified as one of the aforementioned three angles.

[0029] As shown in Fig. 1, a signal indicative of a steering angle  $\phi$  detected by the steering angle sensor 34, a signal indicative of a yaw rate  $\gamma$  detected by the yaw rate sensor 36, and a signal indicative of a vehicle speed  $V$  detected by the vehicle speed sensor 38 are input to the electronic control unit 30. Although not shown in detail in Fig. 1, the electronic control unit 30 includes, for example, a microcomputer having a general construction wherein a CPU, a ROM, a RAM, and an input/output unit are interconnected by a bidirectional common bus.

[0030] As will be described later, according to the flowcharts shown in Figs. 2 and 3, if a reference rotational position of the steering angle sensor 34 has been determined, the electronic control unit 30 calculates a steering angle  $\theta$  on the basis of the determined reference position and a steering angle  $\phi$  detected by the steering angle sensor 34, and calculates a target yaw rate  $\gamma_t$  of the vehicle on the basis of the steering angle  $\theta$ . On the basis of a difference  $\Delta\gamma$  between the target yaw rate  $\gamma_t$  and the yaw rate  $\gamma$  detected by the yaw rate sensor 36, the braking unit 20 controls braking forces applied to the wheels and thereby controls motion of the vehicle.



[0031] On the other hand, if the reference rotational position of the steering angle sensor 34 has not been determined, the electronic control unit 30 provisionally calculates three target yaw rates  $\gamma_1$ ,  $\gamma_2$  and  $\gamma_3$  on the assumption that the steering angle  $\theta$  is equal to  $\phi$ ,  $\phi+360^\circ$  and  $\phi-360^\circ$ , respectively. The electronic control unit 30 then calculates a difference  $\Delta\gamma_1$  between the target yaw rate  $\gamma_1$  and the yaw rate  $\gamma$  detected by the yaw rate sensor 36, a difference  $\Delta\gamma_2$  between the target yaw rate  $\gamma_2$  and the yaw rate  $\gamma$  detected by the yaw rate sensor 36, and a difference  $\Delta\gamma_3$  between the target yaw rate  $\gamma_3$  and the yaw rate  $\gamma$  detected by the yaw rate sensor 36. The braking unit 20 controls braking forces applied to the wheels on the basis of the minimum one of the differences  $\Delta\gamma_1$ ,  $\Delta\gamma_2$  and  $\Delta\gamma_3$ , and thereby controls motion of the vehicle.

[0032] The electronic control unit 30 calculates time averages  $\Delta\gamma_{a1}$ ,  $\Delta\gamma_{a2}$  and  $\Delta\gamma_{a3}$  of absolute values of the differences  $\Delta\gamma_1$ ,  $\Delta\gamma_2$  and  $\Delta\gamma_3$ , determines a reference rotational position of a steering angle  $\phi$  corresponding to the minimum one of the time averages  $\Delta\gamma_{a1}$ ,  $\Delta\gamma_{a2}$  and  $\Delta\gamma_{a3}$  as a neutral position, and then calculates a steering angle  $\theta$  for motion control of the vehicle on the basis of the reference rotational position thus determined and a steering angle  $\phi$  detected by the steering angle sensor 34.

[0033] Next, a motion control routine of the first embodiment will be described with reference to the flowcharts shown in Figs. 2 and 3. A control operation based on the flowchart shown in Fig. 2 is started by closing an ignition switch (not shown) and is repeated at intervals of a predetermined period. At the beginning of the control operation, a flag F indicating whether or not determination of a reference rotational position of the steering angle sensor 34 has been completed is initialized by being reset as 0.

[0034] First of all in a step 10, a signal or the like indicative of a steering angle  $\phi$  detected by the steering angle sensor 34 is read. In a step 20, it is determined whether or not the flag F indicates 1, namely, whether or not determination of a reference rotational position of the steering angle sensor 34 has

been completed. If the result in the step 20 is negative, the control operation proceeds to a step 60. If the result in the step 20 is positive, the control operation proceeds to a step 30.

5 [0035] In the step 30, a steering angle  $\theta$  for controlling motion of the vehicle is calculated on the basis of a reference rotational position determined in the later-described step 200 and a steering angle  $\phi$  detected by the steering angle sensor 34.

[0036] In a step 40, a reference yaw rate  $\gamma_e$  is calculated according to an equation (1) shown below wherein N, H and Kh represent a steering gear ratio, a wheel base, and a stability factor respectively. A target yaw rate  $\gamma_t$  of the vehicle is calculated according to an equation (2) shown below wherein T and "s" represent a time constant and an Laplace operator respectively. A reference yaw rate  $\gamma_e$  may be calculated in consideration of a lateral acceleration Gy of the vehicle so as to take a dynamic yaw rate into account.

15 [0037]  $\gamma_e = V\phi/(1+KhV^2)NH \dots (1)$

[0038]  $\gamma_e = V\phi/(1+Ts) \dots (2)$

[0039] In a step 50, a yaw rate difference  $\Delta\gamma$  is calculated as a difference between the target yaw rate  $\gamma_t$  and a yaw rate  $\gamma$  detected by the yaw rate sensor 36. The control operation then proceeds to a step 300.

20 [0040] In a step 60, the steering angle  $\theta$  is set as a steering angle  $\phi$  detected by the steering angle sensor 34, and a target yaw rate  $\gamma_{t1}$  of the vehicle is calculated according to the aforementioned equations (1) and (2). In a step 70, the steering angle  $\theta$  is set as  $\phi+360^\circ$ , and a target yaw rate  $\gamma_{t2}$  of the vehicle is calculated according to the aforementioned equations (1) and (2). In a step 80, the steering angle  $\theta$  is set as  $\phi-360^\circ$ , and a target yaw rate  $\gamma_{t3}$  of the vehicle is calculated according to the aforementioned equations (1) and (2).

25 [0041] In a step 90, yaw rate differences  $\Delta\gamma_1$ ,  $\Delta\gamma_2$  and  $\Delta\gamma_3$  corresponding to the target yaw rates  $\gamma_1$ ,  $\gamma_2$  and  $\gamma_3$  respectively are calculated as differences between the yaw rate  $\gamma$  detected by the yaw rate sensor 36 and the target yaw rates  $\gamma_{t1}$ ,  $\gamma_{t2}$

and  $\gamma_{t3}$  respectively. In a step 100, the minimum one of the yaw rate differences  $\Delta\gamma_1$ ,  $\Delta\gamma_2$  and  $\Delta\gamma_3$  is set as the yaw rate difference  $\Delta\gamma$ .

[0042] In the step 200, a reference rotational position of the steering angle sensor 34 is determined according to the routine shown in Fig. 3. In the step 300, according to the gist known in the technical field of the invention, braking forces applied to the wheels are controlled on the basis of the yaw rate difference  $\Delta\gamma$  such that the yaw rate difference  $\Delta\gamma$  decreases. Thereby, motion control of the vehicle is performed so as to ensure running stability thereof.

[0043] Next, a routine that is executed in the step 200 to determine a reference rotational position of the steering angle sensor 34 will be described with reference to Fig. 3.

[0044] First of all in a step 205, it is determined whether or not "n" (a positive, constant integer) cycles have passed since the start of the control operation. If the result in the step 205 is negative, the control operation proceeds to the step 300 immediately. If the result in the step 205 is positive, the control operation proceeds to a step 210.

[0045] In the step 210, time averages  $\Delta\gamma_{a1}$ ,  $\Delta\gamma_{a2}$  and  $\Delta\gamma_{a3}$  of absolute values of the yaw rate differences  $\Delta\gamma_1$ ,  $\Delta\gamma_2$  and  $\Delta\gamma_3$  in the first to the latest "n" cycles are calculated. In a step 215, the maximum, medium and minimum ones of the time averages  $\Delta\gamma_{a1}$ ,  $\Delta\gamma_{a2}$  and  $\Delta\gamma_{a3}$  are defined as  $\Delta\gamma_{max}$ ,  $\Delta\gamma_{med}$  and  $\Delta\gamma_{min}$  respectively.

[0046] In a step 220, a reference value  $\Delta\gamma_0$  is calculated according to an equation (3) shown below wherein  $\Delta\gamma_b$  and  $\Delta\gamma_c$  are positive constants. In the step 220, it is determined whether or not the minimum time average  $\Delta\gamma_{min}$  is equal to or smaller than the reference value  $\Delta\gamma_0$ , namely, whether or not the behavior of the vehicle is relatively stable. If the result in the step 220 is negative, the control operation proceeds to the step 300 immediately. If the result in the step 220 is positive, the control operation proceeds to a step 225.

$$[0047] \quad \Delta\gamma_0 = \Delta\gamma_b \times V + \Delta\gamma_c \dots (3)$$

[0048] In the step 225, it is determined whether or not a difference between the maximum time average  $\Delta y_{\max}$  and the medium time average  $\Delta y_{\text{med}}$  is larger than a reference value  $\Delta y_e$  (a positive constant) while a difference between the medium time average  $\Delta y_{\text{med}}$  and the minimum time average  $\Delta y_{\min}$  is larger than the reference value  $\Delta y_e$ . If the result in the step 225 is negative, the control operation proceeds to the step 300. If the result in the step 225 is positive, the control operation proceeds to a step 280. The determination in the step 225 is made to exclude a situation in which a relationship in magnitude among three steering angles estimated from the detected steering angle  $\phi$  does not correspond to a relationship in magnitude among the time averages  $\Delta y_1$ ,  $\Delta y_2$  and  $\Delta y_3$  as a result of calculation of time averages of absolute values of yaw rate differences.

[0049] In the step 280, a reference rotational position of the steering angle  $\phi$  used for calculation of the yaw rate differences  $\Delta y_1$  to  $\Delta y_3$  corresponding to the minimum time average  $\Delta y_{\min}$  is determined as a neutral position. In a step 285, the flag F1 is set as 1. The control operation then proceeds to the step 300.

[0050] Thus, according to the first embodiment illustrated in the drawings, if determination of a reference rotational position of the steering angle sensor 34 has not been completed, the result in the step 20 is negative. Then in the steps 60 to 80, three target yaw rates  $\gamma_1$ ,  $\gamma_2$  and  $\gamma_3$  of the vehicle are provisionally calculated on the assumptions that the steering angle  $\theta$  is  $\phi$ ,  $\phi+360^\circ$  and  $\phi-360^\circ$  respectively. The true steering angle  $\theta$  may be  $\phi$ ,  $\phi+360^\circ$  or  $\phi-360^\circ$ . In the step 90, differences between a yaw rate  $\gamma$  detected by the yaw rate sensor 36 and the target yaw rates  $\gamma_1$ ,  $\gamma_2$  and  $\gamma_3$  are calculated. In the step 100, the minimum one of the differences  $\Delta y_1$ ,  $\Delta y_2$  and  $\Delta y_3$  is defined as the yaw rate difference  $\Delta y$ . In the step 300, braking forces applied to the wheels are controlled on the basis of the yaw rate difference  $\Delta y$  such that the yaw rate difference  $\Delta y$  decreases, whereby motion of the vehicle is controlled.

[0051] Accordingly, even if the behavior of the vehicle has deteriorated in a situation where determination of a reference rotational position of the steering angle

sensor 34 has not been completed, motion of the vehicle can be controlled on the basis of the minimum one of the yaw rate differences  $\Delta\gamma_1$ ,  $\Delta\gamma_2$  and  $\Delta\gamma_3$ , namely, a yaw rate difference that is most likely to correspond to a true steering angle. Thus, the behavior of the vehicle can be stabilized reliably.

5           [0052] Immediately after takeoff of the vehicle, determination of a reference rotational position of the steering angle sensor 34 has not been completed. In this situation, a substantial deterioration of the behavior of the vehicle is seldom caused. The magnitude of the minimum one of the yaw rate differences  $\Delta\gamma_1$ ,  $\Delta\gamma_2$  and  $\Delta\gamma_3$  is small. Therefore, even in the case where the minimum one of the yaw rate  
10 differences  $\Delta\gamma_1$ ,  $\Delta\gamma_2$  and  $\Delta\gamma_3$  does not correspond to a true steering angle, motion control of the vehicle based on the minimum one of the differences does not cause excessive inconvenience to the traveling of the vehicle.

          [0053] According to the first embodiment illustrated in the drawings, if determination of a reference rotational position of the steering angle sensor 34 has  
15 not been completed, time averages  $\Delta\gamma_{a1}$ ,  $\Delta\gamma_{a2}$  and  $\Delta\gamma_{a3}$  of absolute values of the yaw rate differences  $\Delta\gamma_1$ ,  $\Delta\gamma_2$  and  $\Delta\gamma_3$  are calculated in the step 210 of the reference rotational position determining routine starting from the step 200. In the steps 215 to 280, the reference rotational position of a steering angle  $\phi$  corresponding to the minimum one of the time averages  $\Delta\gamma_{a1}$ ,  $\Delta\gamma_{a2}$  and  $\Delta\gamma_{a3}$  is determined as a neutral  
20 position. Thereafter, a steering angle  $\theta$  for controlling motion of the vehicle is calculated on the basis of the reference rotational position thus determined and the steering angle  $\phi$  detected by the steering angle sensor 34. Therefore, there is no need to provide any means for storing a steering angle even while the ignition switch is off. A reference rotational position of the steering angle sensor 34 can be  
25 determined as a neutral position for steering even unless the vehicle is traveling straight on at a constant speed.

          [0054] Especially according to the embodiment illustrated in the drawings, time averages  $\Delta\gamma_{a1}$ ,  $\Delta\gamma_{a2}$  and  $\Delta\gamma_{a3}$  of absolute values of the yaw rate differences  $\Delta\gamma_1$ ,  $\Delta\gamma_2$  and  $\Delta\gamma_3$  in the first to the latest "n" cycles are calculated in the step 210.

In the steps 215 to 280, the reference rotational position of a steering angle  $\phi$  corresponding to the minimum one of the time averages  $\Delta\gamma_1$ ,  $\Delta\gamma_2$  and  $\Delta\gamma_3$  is determined as a neutral position. Therefore, in comparison with a case where the reference rotational position of a steering angle  $\phi$  corresponding to the minimum one of the yaw rate differences  $\Delta\gamma_1$ ,  $\Delta\gamma_2$  and  $\Delta\gamma_3$  instead of the minimum one of the time averages  $\Delta\gamma_1$ ,  $\Delta\gamma_2$  and  $\Delta\gamma_3$  is determined as a neutral position, it is possible to determine a reference rotational position of the steering angle sensor 34 more precisely.

[0055] In the embodiment illustrated in the drawings, the maximum, medium and minimum ones of the time averages  $\Delta\gamma_1$ ,  $\Delta\gamma_2$  and  $\Delta\gamma_3$  are defined as  $\Delta\gamma_{\max}$ ,  $\Delta\gamma_{\text{med}}$  and  $\Delta\gamma_{\min}$  respectively in the step 215. If it is determined in the step 220 that the minimum one  $\Delta\gamma_{\min}$  of the time averages is equal to or smaller than the reference value  $\Delta\gamma_0$  and if it is determined in the step 225 that a difference between the maximum one  $\Delta\gamma_{\max}$  of the time averages and the medium one  $\Delta\gamma_{\text{med}}$  of the time averages is larger than the reference value  $\Delta\gamma_c$  while a difference between the medium one  $\Delta\gamma_{\text{med}}$  of the time averages and the minimum one  $\Delta\gamma_{\min}$  of the time averages is larger than the reference value  $\Delta\gamma_c$ , the reference rotational position of a steering angle  $\phi$  used for calculation of a yaw rate difference corresponding to the minimum one  $\Delta\gamma_{\min}$  of the time averages is determined as a neutral position in the step 280. Therefore, in comparison with a case where the determination in the step 220 or the step 225 is not made, the possibility of determining a reference rotational position of the steering angle sensor 34 imprecisely as a result of the influence of the behavior of the vehicle or calculation of the time averages of the absolute values of the yaw rate differences can be reduced reliably.

[0056] According to the embodiment illustrated in the drawings, the reference value  $\Delta\gamma_0$  in the determination of the step 220 is calculated according to the aforementioned equation (3) while the vehicle speed  $V$  is taken into account. Therefore, in comparison with a case where the reference value  $\Delta\gamma_0$  is set as a

constant without taking the vehicle speed  $V$  into account, the reference value  $\Delta\gamma_0$  can be set more suitably in accordance with a vehicle speed. As a result, a reference rotational position of the steering angle sensor 34 can be determined while suitably excluding the influence of the behavior of the vehicle.

5 [0057] Fig. 4 is a flowchart showing a reference rotational position determining routine in a vehicular motion control apparatus in accordance with the second preferred embodiment of the invention. Referring to Fig. 4, steps identical with those in Fig. 3 are accompanied by the same step numbers.

10 [0058] In the second embodiment, although not shown in Fig. 4, processings in the steps 10 to 100 and the step 300 of the vehicular motion control routine are performed substantially in the same manner as in the aforementioned first embodiment. Further, as shown in Fig. 3, processings in the steps 205, 210, 280 and 285 of the reference rotational position determining routine starting from the

15 aforementioned first embodiment.

[0059] In a step 250 subsequent to the step 210, steering angle deviation amounts  $\Delta\gamma s1$ ,  $\Delta\gamma s2$  and  $\Delta\gamma s3$  are calculated on the basis of the time averages  $\Delta\gamma a1$ ,  $\Delta\gamma a2$  and  $\Delta\gamma a3$  respectively, according to equations (4) to (6) shown below. In a

20 amounts  $\Delta\gamma s1$ ,  $\Delta\gamma s2$  and  $\Delta\gamma s3$  are defined as  $\Delta\gamma_{max}$ ,  $\Delta\gamma_{med}$  and  $\Delta\gamma_{min}$  respectively.

$$[0060] \Delta\gamma s1 = \Delta\gamma a1 \times (NH/V) \dots (4)$$

$$[0061] \Delta\gamma s2 = \Delta\gamma b2 \times (NH/V) \dots (5)$$

$$[0062] \Delta\gamma s3 = \Delta\gamma c3 \times (NH/V) \dots (6)$$

25 [0063] In a step 260, it is determined whether or not the minimum one of the steering angle deviation amounts is equal to or smaller than a reference value  $\Delta\gamma s_0$  (a positive constant), namely, whether or not the vehicle is in a relatively stable traveling state. If the result in the step 260 is negative, the control operation proceeds to the step 300. If the result in the step 260 is positive, the control operation proceeds to a step 265. As is the case with the reference value  $\Delta\gamma_0$  of the

aforementioned first embodiment, the reference value  $\Delta y_{s0}$  may also be calculated as a function of the vehicle speed  $V$ .

[0064] In the step 265, it is determined whether or not the maximum one  $\Delta y_{\max}$  of the steering angle deviation amounts is larger than a reference value  $\Delta y_{s1}$  (a positive constant) while the medium one  $\Delta y_{\text{med}}$  of the steering angle deviation amounts is larger than a reference value  $\Delta y_{s2}$  (a positive constant smaller than  $\Delta y_{s1}$ ). If the result in the step 265 is negative, the control operation proceeds to the step 300 immediately. If the result in the step 265 is positive, the processings in the steps 280 and 285 are performed substantially in the same manner as in the aforementioned first embodiment.

[0065] As is the case with the step 225 of the aforementioned first embodiment, the determination in the step 265 is made to exclude a situation in which a relationship in magnitude among three steering angles estimated from the detected steering angle  $\phi$  does not correspond to a relationship in magnitude among the steering angle deviation amounts  $\Delta y_{s1}$ ,  $\Delta y_{s2}$  and  $\Delta y_{s3}$  as a result of calculation of time averages of absolute values of yaw rate differences.

[0066] Thus, the second embodiment illustrated in Fig. 4 can substantially achieve the same operation and effect as the aforementioned first embodiment. In particular, according to the second embodiment, the steering angle deviation amounts  $\Delta y_{s1}$ ,  $\Delta y_{s2}$  and  $\Delta y_{s3}$  are calculated on the basis of the time averages  $\Delta y_{a1}$ ,  $\Delta y_{a2}$  and  $\Delta y_{a3}$  respectively in the step 250. In the step 255, the maximum, medium and minimum ones of the steering angle deviation amounts  $\Delta y_{s1}$ ,  $\Delta y_{s2}$  and  $\Delta y_{s3}$  are defined as  $\Delta y_{\max}$ ,  $\Delta y_{\text{med}}$  and  $\Delta y_{\min}$  respectively. As for these values, the determinations in the steps 260 and 265 are made. Therefore, in comparison with a case where the determination in the step 260 or 265 is not made, the reference rotational position of the steering angle sensor 34 can be determined more precisely.

[0067] The specific embodiments of the invention have been described hitherto in detail. However, it would be obvious to those skilled in the art that the



invention is not limited to the aforementioned embodiments, and that more varieties of embodiments are possible within the scope of the invention.

[0068] For example, the vehicle state quantity represents yaw rate in the aforementioned embodiments. However, the vehicle state quantity may be any vehicle state quantity associated with steering angle, for example, lateral acceleration Gy of the vehicle or wheel speed difference  $\Delta V_w$  between the front-left and front-right wheels. A target lateral acceleration Gyt of the vehicle may be calculated according to an equation (7) shown below. A target wheel speed difference  $\Delta V_{wt}$  between the front-left and front-right wheels may be calculated as a tread Tf according to an equation (8) shown below.

$$[0069] \quad Gyt = \gamma_t V \dots (7)$$

$$[0070] \quad \Delta V_{wt} = \gamma_t Tf \dots (8)$$

[0071] In the aforementioned embodiments, if determination of a reference rotational position of the steering angle sensor 34 has been completed, the steering angle  $\theta$  for controlling motion of the vehicle is calculated on the basis of the determined reference rotational position and the steering angle  $\phi$  detected by the steering angle sensor 34 in the step 30. The target yaw rate  $\gamma_t$  of the vehicle is calculated in the step 40, and the yaw rate difference  $\Delta \gamma$  is calculated in the step 50. In the step 300, motion of the vehicle is controlled on the basis of the yaw rate difference  $\Delta \gamma$ . However, motion control, which is performed if determination of a reference rotational position of the steering angle sensor 34 has been completed, is not limited to a control operation based on the yaw rate difference  $\Delta \gamma$ . As long as the steering angle  $\theta$  for motion control which is calculated on the basis of the determined reference rotational position and the steering angle  $\phi$  detected by the steering angle sensor 34 is used, motion control may be any vehicle control operation that is known in the technical field of the invention.

[0072] In the aforementioned respective embodiments, the lock-to-lock number of revolutions of the steering system is 3. However, the lock-to-lock number of revolutions may be a value other than 3. The steering angle sensor 34

may have such a resolution that the reference rotational position thereof rotates by a rotational angle larger than  $360^\circ$  per one turn of the steering shaft. In this case, a target vehicle state quantity such as a target yaw rate is calculated the same number of times as the reference rotational position of the steering angle sensor 34 rotates by  $360^\circ$  within a lock-to-lock rotational range of the steering shaft.

[0073] For instance, if the lock-to-lock number of revolutions is 3 while the steering angle sensor 34 is twice as high in resolution as in the embodiments illustrated in the drawings, the true steering angle  $\theta$  may be  $\phi$ ,  $\phi+180^\circ$ ,  $\phi+360^\circ$ ,  $\phi-180^\circ$  or  $\phi-360^\circ$ . Therefore, a target vehicle state quantity is calculated as to each of the steering angles  $\phi$ ,  $\phi+180^\circ$ ,  $\phi+360^\circ$ ,  $\phi-180^\circ$  and  $\phi-360^\circ$ .